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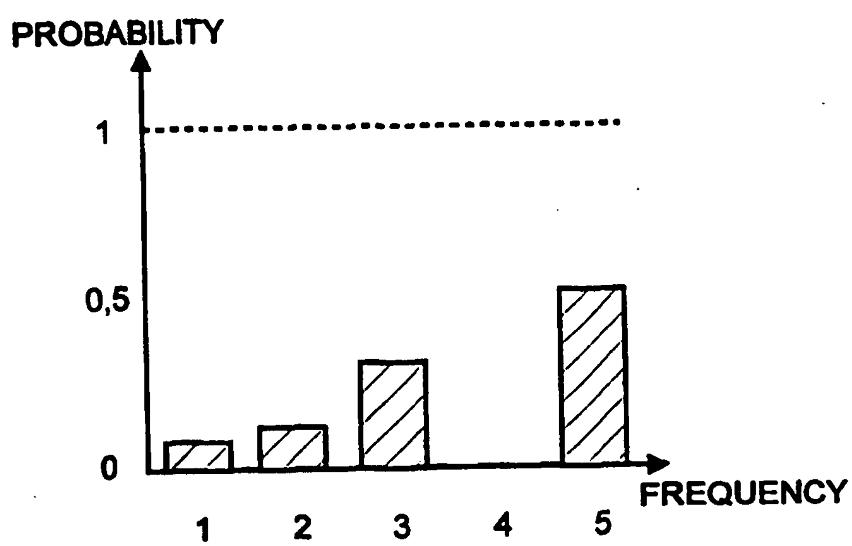
(57) Abstract



The idea of the invention is to achieve optimum levelling out of interference by controlling the usage distribution of hopping states. Usage is not necessarily uniformly distributed, but certain hopping states are used more frequently than others. The distribution of hopping states may, for example, be determined by minimising a pre-determined penalty function. The performance of the distribution can be monitored, for example, on the basis of network geometry, predicted or measured field strength, and traffic data. Once the frequency usage distribution is determined, it is possible to specify the frequency-hopping pattern to be used for the connection. The higher the probability that a frequency is used for a given connection, as determined by the optimisation, the morefrequently a frequency is used in the hopping sequence.

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LEVELLING OUT OF INTERFERENCE IN A MOBILE NETWORK USING A HOPPING METHOD

Field of the invention

The present invention relates to levelling out of interference in a mobile network using the hopping method.

Background of the invention

In mobile communications systems, mobile stations and base stations are capable of setting up connections using the so-called radio interface channels. Various requirements, depending on the type of data involved, are imposed on such connections relating to the data transmission rate, the accuracy of the data, and transmission delay.

A specific frequency range is always allocated for use by the mobile network. This frequency range is subdivided into channels whose transmission capacity is optimised to match the services provided by the mobile network. To ensure sufficient capacity within the limited frequency range allocated for the mobile network, the channels available must be re-used. For this purpose, the system coverage area is divided into cells consisting of the coverage areas of the individual base stations, which is why such systems are often also referred to as cellular radio systems.

Through the radio connection, mobile stations have access to the services provided by the mobile network. Figure 1 outlines the structure of a known mobile network system. The network includes a number of inter-connected Mobile Services Switching Centres MSC. A mobile services switching centre MSC is capable of setting up connections with other mobile services switching centres MSC or other telecommunications networks, such as the Integrated Services Digital Network ISDN, the Public Switched Telephone Network PSTN, the Internet, the Packet Data Network PDN, the Asynchronous Transfer Mode ATM and the General Packet Radio Service GPRS. Each mobile services switching centre has several base station controllers BSC connected to it. Similarly, each base station controller is connected to several base stations. The base stations are capable of setting up connections with mobile stations MS. The Network Management System NMS is used for collecting data on the network and re-programming the network elements.

The air interface between the base stations and mobile stations can be divided into channels in a number of different ways. Known methods include at least Time Division Multiplexing TDM, Frequency Division Multiplexing FDM, and Code Division Multiplexing CDM. In TDM systems, the allocated bandwidth is divided into sequential time-slots. A specific number of sequential time-slots constitute a periodically recurring time frame. The channel is defined by the time slot used in the time frame. In FDM systems the channel is defined by the frequency used, and in CDM systems by the frequency-hopping pattern or hashing code. Various combinations of the division methods described above can also be used.

Figure 2 provides an example of a known FDM/TDM division. In the figure, the vertical axis represents frequency and the horizontal axis time. The allocated frequency range is divided into six frequencies denoted by F1 through F6. In addition, the frequency channel consisting of each individual frequency is sub-divided into recurring time frames made up of 8 sequential time-slots. The channel is always defined by the pair (F, TS), where F is frequency and TS is the time-slot, used in the time frame.

To maximise capacity, the channels must be re-used in cells that are located as close to one another as possible, providing, however, that the quality of the connections using the channels remains adequate. The quality of the connection is affected by the sensitivity of the transmitted information to the transmission errors occurring in the radio channel and the quality of the radio channel. Resilience against signal transmission errors depends on the properties of the information being transferred and can be improved by processing the information by means of channel coding and interleaving before the data are sent and by using re-transmission of erroneous transmission frames.

The quality of the radio channel is, in particular, affected by the extent of mutual interference caused by the connections, which, in turn, depends on the channels used by the connections, the geographical distribution of the connections, and the transmission power used. These factors can be influenced by a systematic allocation of the channels to the various cells with due regard to such interference, by regulating the transmission power, and by averaging the interference experienced by the various connections.

Even if channel allocation is successful, different connections are exposed to different levels of interference. As a result, some connections may suffer from interference that severely affects their quality while other connections could, at the same time, tolerate a higher level of interference. A channel may be allocated, if the signal-to-noise ratio achieved by the connections set up for the channel involved falls below a predefined limit for only a small percentage (e.g. 5 per cent), of the connections. If the fluctuations in the level of interference between various connections can be reduced, the said quality of connection can be achieved at a denser re-use rate of the channel, which increases system capacity.

Known methods for levelling out relative interference between connections include frequency hopping, used in the FDM systems, and time-slot hopping, used in the TDM systems. These and other methods based on channel alteration will be collectively referred below as channel hopping methods. In CDM systems, differences in interference between connections can be suppressed by using hashing codes of sufficient diversity. However, in this method, all the connections make use of the same frequency, which increases average cross-interference considerably.

With frequency hopping, the frequency used by the connection keeps changing at short intervals. Thus, the transmission frequency serves as the hopping quantity. The methods can be divided into slow and fast frequency hopping. In fast frequency hopping, the connection frequency is changed more often than the carrier wave frequency. In slow frequency hopping, the connection frequency is changed less often than the carrier wave frequency.

For example, in the known GSM system, frequency hopping is implemented so that an individual burst is always transmitted at one frequency and the burst in the following time-slot at another. As a result, an individual burst can be subjected to a high level of interference. Thanks to channel coding and interleaving, the required quality of connection can be achieved by ensuring that a sufficiently high percentage of the bursts are transmitted free of significant interference. With frequency hopping, this requirement can be satisfied specifically for each individual connection, even if some of the bursts were subjected to major interference.

Figure 3 provides an illustration of a frequency-hopping arrangement with the frequencies used for the various bursts. Four

frequencies, F1 through F4, are allocated for use by the cell. The hopping pattern is cyclic in that the cell transmits the sequential bursts at the frequencies F4, F2, F3, and F1 in that particular order and that this cycle is repeated once completed. Because the length of the cycle is 4 bursts, a single connection in a system using eight time-slot frames shown as an example in Figure 2 uses the same frequency only for every fourth burst. As a result, the fadings occurring in the connection between the mobile station and the base station are averaged over the individual connections. With frequency hopping, the best levelling-out performance for interference is achieved when the frequency-hopping patterns used by cells close to one another are mutually independent. This is achieved by employing carefully selected cyclic or pseudo-random frequency-hopping patterns.

In time-slot hopping, the hopping quantity is the TDMA frame time-slot used for the connection. Figure 4 illustrates a time-slot hopping pattern where the signal is transmitted in sequential frames in time-slots 1, 4, 0, and 6, after which the cycle is repeated. To achieve the best possible performance, the hopping patterns used in time-slot hopping must also be mutually independent in cells close to one another.

To maximise the benefits offered by the hopping methods, steps must be taken to optimise the hopping pattern. Dynamic determination of the frequencies used for hopping is the best-known method.

U.S. Patent 5,541,954 (Emi) describes a frequency-hopping method for wideband telecommunications systems where frequency is changed according to a pre-determined hashing code. This method monitors errors in the received data and calculates the number of errors detected at a given hopping frequency. When the number of errors at a given hopping pattern frequency exceeds a pre-determined limit, the frequency is changed to another frequency that is available at that particular moment.

In the method in accordance with the said publication, the set of frequencies in the frequency-hopping pattern is essentially changed as a function of the errors detected. However, the frequencies in the frequency set are used equally.

U.S. Patent 5,394,433 (Bantz et al.) describes a method for controlling and performing frequency-hopping operations. Specifically, the invention introduced in the publication relates to the determination of the frequency-hopping pattern, detection of interference, and changing of the

frequency-hopping pattern. Frequency hopping is defined in terms of a set of hopping frequencies and a hopping code controlling the use of the frequencies, of which only the set of hopping frequencies is modified. The frequencies are used equally.

U.S. Patent 5,425,049 (Dent) describes a method for increasing interference diversity by using staggered delays between frequency hops in the neighbouring base stations. The frequency used for the link between the mobile station and the base station changes according to a pseudo-random hopping pattern following uniform usage distribution.

The number of users in the mobile networks and the use of applications requiring wide bandwidths, such as multimedia applications, are growing rapidly. Consequently, the volume of information transmitted in the system increases, causing a higher average level of interference within the system. As a result, more stringent requirements are being imposed on methods to level out interference, and the prior art methods developed for this purpose are no longer capable of providing the required performance.

The aim of the present invention is to resolve the problem described above. This is accomplished by means of the method described in the independent patent claims.

Brief description of the invention

The idea of the invention is to optimise the levelling-out of interference by adjusting the usage distribution of the hopping states. Usage distribution is not necessarily uniform; instead, the various hopping states have varying usage rates in the hopping pattern. In other words, some hopping states are used more frequently than others.

Preferably, the distribution of the hopping states is determined by minimising a pre-defined penalty function. For example, optimum distribution can be measured based on network geometry, predicted or measured field strengths, and traffic data.

Once the usage distribution of the frequencies is determined, it is possible to determine the frequency-hopping patterns for the connection to be used. The higher the probability that a frequency will be used for a given connection, as defined by the optimisation, the more frequently a frequency is used in the hopping sequence.

When used for fixed channel allocation, the invention provides a frequency planning scheme used to allocate frequency distributions and the hopping sequences for their implementation to the transceivers in the cell. In the case of dynamic allocation, the invention provides a method for dynamically changing the distribution of frequencies available for the connections in the cell involved and for defining the hopping sequences.

List of drawings

The invention is explained in more detailed with reference to the following drawings, where

Figure 1 illustrates sections of a mobile network essential to the invention;
Figure 2 illustrates the FDM/TDM distribution;
Figure 3 illustrates, by way of an example, a frequency-hopping pattern for a radio connection as a function of time;
Figure 4 illustrates, by way of an example, a time-slot hopping pattern for a radio connection in a TDMA system; and
Figures 5A, 5B and 5C illustrate distributions of frequency usage.

Detailed description of the invention

The main element of change to current hopping methods introduced by the invention is outlined in figures 5A, 5B, and 5C. While the figures use a frequency-hopping system as an example, the invention is not limited to this system; instead, any hopping method, such as time-slot hopping, can be substituted for frequency hopping.

Figure 5A shows a prior art arrangement where frequency hopping is not used. There, the connection uses only frequency 2. Figure 5B illustrates a prior art arrangement where the connection uses a frequency-hopping sequence consisting of two frequencies, 2 and 5. Both frequencies are used equally, i.e. frequency 2 is used for 50 per cent of the time and frequency 5 for the remaining 50 per cent. Figure 5C shows an arrangement in accordance with the present invention, where the hopping frequencies for frequency hopping are used according to a free probability distribution. In the example shown in the figure, frequency 1 is used for 10 per cent of the time, frequency 2 for 15 per cent, frequency 3 for 25 per cent, and frequency 5 for 50 per cent of the time. Consequently, the connection can make more

efficient use of frequencies with a low level of interference without, however, inducing an excessive increase in the level of interference for these frequencies. Thus, an improved levelling-out of interference for the system as a whole is achieved.

Determining the frequency usage distribution is an optimisation task. In the design stage, the optimum distribution can be assessed by means of network geometry, predicted or measured field strengths, and penalty functions based on traffic data. For example, the expectation value *E(BER(i))* for the Bit Error Ratio BER for connection *i* can be used as the penalty function:

$$E(BER(i)) = \sum_{j \neq i} b_{ij} \cdot P(k(i) = k(j)) = \sum_{j \neq i} b_{ij} \cdot \sum_{k} P(k_i = k) \cdot P(k_j = k), \quad (1)$$

where b_{ij} is the expectation value for bit error ratio caused by connection *j* to connection *i* when the two connections use the same channel, and *P(k(i)=k(j))* is the probability for connections *i* and *j* using the same channel.

For example, optimisation can be used for minimising the highest bit error ratio $\max_i (E(BER(i))$ of the connections or for maximising the number of connections attaining bit error ratios below a specific limit maxBER, or, more generally, the probability for the limit maxBER not being exceeded.

One important benefit offered by the arrangement in accordance with the present invention is that the state space for the use of frequencies is continuous. This makes it possible to use optimisation methods based on differential calculus, such as the gradient method. This is of benefit, especially, to systems using dynamic channel allocation where channels are allocated to cells dynamically in response to traffic requirements. Then, the system knows at the moment of change in the traffic demand how the frequency distributions for the various connections should be changed, making it possible to effect updating very quickly. At low network loads, fixed frequencies can be allocated to the connections. When the load increases, several frequencies will be placed in service and used on a non-uniform distribution basis.

Once the usage distribution is defined for the frequencies, it is possible to determine the frequency-hopping pattern for the connection. The

higher the probability that a frequency will be used for a given connection, as determined by optimisation, the more frequently a frequency is used in the hopping sequence. For example, if the frequency usage distribution defined for a connection is

Fi	P(Fi)
F1	0.1
F2	0.15
F3	0.25
F4	0
F5	0.5

the frequency-hopping pattern implementing the desired usage distribution is (F1, F1, F2, F2, F2, F3, F3, F3, F3, F3, F5, F5, F5, F5, F5, F5, F5, F5, F5, F5). The signal hops between these 20 elements in the list in a pseudo-random or cyclic sequence. If the distribution is more complex, the frequency-hopping pattern designed to effect the desired usage distribution must be defined approximately. The accuracy of the resulting frequency distribution is determined by the maximum length of the frequency list.

Naturally, the definition can be carried out in various ways, the method described above being just one example.

Let us examine the bit error ratios for two connections in a situation where only frequencies F1 and F2 are in use. When the connections use the same channel, the bit error ratio caused by the connections to each other is b=0.05. For the sake of clarity, interference from neighbouring channels is ignored in this example. Interference from other connections is shown in the following table:

	BER(F1)	BER(F2)
con. 1	c11 = 0.01	c12 = 0.075
con. 2	c21 = 0.015	c22 = 0.1

Assuming that the joint distribution of frequencies is

con. 2/con. 1	F1	F2
F1	f11	f12
F2	f21	f22

the approximate bit error ratios for the connections are obtained as BER(connection 1)= f11*(b+c11) + f12*c12 + f21*c11 + f22*(b+c12) and BER(connection 2)= f11*(b+c21) + f12*c21 + f21*c22 + f22*(b+c22).

Let us first examine a situation where the use of frequencies by the connections is not synchronised, but they are independent of each other. An example of free distribution in accordance with the present invention is as follows

	P(F1)	P(F2)
con. 1	0.82	0.18
con. 2	0.92	0.08

Because the use of frequencies by the connections is not synchronised, the joint distribution of frequencies is

con. 2/con. 1	F1	F2
F1	0.7544	0.1656
F2	0.0656	0.0144

Similarly, a frequency scheme for uniform distribution is

	P(F1)	P(F2)
con. 1	0.5	0.5
con. 2	0.5	0.5

which gives a joint distribution of

con. 2/con. 1	F1	F2
F1	0.25	0.25
F2	0.25	0.25

With fixed, non-hopping frequency allocation, such as the allocation (F1, F2) (F1 for connection 1 and F2 for connection 2), the frequency distribution is

	F1	F2
con. 1	1	0
con. 2	0	1

and the joint distribution of frequencies is

con. 2/con. 1	F1	F2
F1	0	0
F2	1	0

The expectation values for the bit error ratios for connections 1 and 2 at different allocations are shown in the following table:

BER	general	uniform	fixed			
			(F1,F1)	(F1,F2)	(F2,F1)	(F2,F2)
con. 1	0.0601	0.0675	0.0600	0.0750	0.01	0.1250
con. 2	0.0602	0.0825	0.0650	0.0150	0.1	0.1500

The table indicates that, in this example, general distribution yields an improvement of approximately 7 per-cent in the maximum value of the bit error ratio compared to the frequency schemes for non-hopping and uniform distribution.

If the frequencies used simultaneously by different connections can be synchronised, major benefits are obtained. This makes it possible to take

administrative steps to prevent two mutually interfering connections from using the same channel.

Generally, the use of a frequency by N connections can be illustrated by the N-dimensioned tensor $f^{i_1,i_2,i_3,\ldots,i_N}$, whose element $f^{i_1,i_2,i_3,\ldots,i_N}_{k_1,k_2,k_3,\ldots,k_N}$ represents the probability for connections i_1, i_2, i_3, ..., i_N simultaneously using the frequencies k_1, k_2, k_3, ..., k_N. For each tensor element, i.e. the frequency state of the connection, there is a specific interference for the connection. If the use of frequencies for various connections can be co-ordinated, it is possible to block the frequency states in which the connections interfere most with one another.

Let us now examine synchronised frequency hopping where the frequency combination for connections can be controlled. An example of the joint distribution of free synchronised frequency usage in accordance with the present invention is

con. 2/con. 1	F1	F2
F1	0	0.6
F2	0.4	0

Similarly, the joint distribution of frequencies of a conventional synchronised frequency hopping using uniform distribution is

con. 2/con. 1	F1	F2
F1	0	0.5
F2	0.5	0

Using synchronised frequency schemes, the equations presented above yield the following expectation values for bit error ratios:

BER	general	uniform
con. 1	0.0490	0.0425
con. 2	0.0490	0.0575

The table indicates that, in this example, general distribution yields an improvement of approximately 15 per cent in the maximum value of the bit error ratio compared to the frequency schemes for non-hopping and uniform distribution.

For the sake of clarity, the examples given in this application involve systems that use only two frequencies. The benefit offered by frequency-hopping methods increases with the increase in the number of frequencies used. Similarly, the increase in the size of the state space provided by an arrangement in accordance with the present invention and available for optimisation leads to greater benefits as the number of available frequencies grows.

The invention can be used with various channel allocation methods. Known channel allocation methods are Fixed Channel Allocation FCA, Dynamic Channel Allocation DCA, and Hybrid Channel Allocation HCA based on a combination of FCA and DCA. The idea with fixed channel allocation is to assign the channels available to the system to the individual cells in accordance with the frequency assignment scheme to be prepared before the system is commissioned. In dynamic channel allocation, all the channels are placed in a channel pool from which the best channel, as defined by some pre-determined criterion, is selected for use. In hybrid channel allocation, some of the channels available to the system are assigned to the individual cells on the FCA basis while the rest are placed in a channel pool for subsequent dynamic allocation to any cell. The various methods are described in fairly good detail in the publication "Channel Assignment Schemes for Cellular Mobile Telecommunication Systems: A Comprehensive Survey", IEEE Personal Communications, pp. 10-31, June 1996, by I. Katzela and M. Naghshineh.

For fixed channel allocation, the invention provides a method for frequency scheme preparation, by which frequency distributions and the hopping sequences for their implementation are allocated to transceivers. For dynamic allocation, the invention provides a method for dynamically changing the distribution of frequencies used by the cell and for defining the hopping sequences.

The present invention allows more efficient use of the frequency bandwidth. In addition, with dynamic allocation, the frequency-hopping pattern may depend on the traffic load, which makes it possible to optimise

the use of the bandwidth for the traffic at any particular moment. As extremes, the method covers uniform usage of all the frequencies in the hopping pattern as well as a situation where hopping is not used. Thus, no algorithm to decide whether hopping is used or not is required.

In the foregoing, the invention has been explained with regard to a system using frequency hopping. However, the invention is not limited to this but can be used together with other hopping methods such as time-slot hopping.

Claims

1. A method for levelling out interference in a mobile network that comprises at least mobile stations and base stations, that enables the establishment of a radio connection between a mobile station and a base station and that uses a hopping method for levelling out interference such as a frequency or time-slot hopping method, characterized in that

determining hopping states belonging to the hopping pattern of a connection;

determining usage probabilities of varying values for the hopping states, and

determining a hopping pattern essentially implementing the usage probability distribution.

2. A method in accordance with patent claim 1, characterized in that the density functions for the probability of usage of the hopping states are defined by means of optimisation.

3. A method in accordance with patent claim 2, characterized in that the density functions are defined by minimising a function being composed of error probabilities for the connections in the system.

4. A method in accordance with patent claim 2, characterized in that information on the network geometry, field strength and traffic volume is used in the optimisation.

5. A method in accordance with patent claim 4, characterized in that the information on field strength consists of a theoretical prediction of field strength.

6. A method in accordance with patent claim 4, characterized in that the information on field strength consists of the result of a measurement on field strength.

7. A method in accordance with patent claim 4, characterized in that the information on traffic volume consists of a predicted traffic volume.

8. A method in accordance with patent claim 4, characterized in that the information on traffic volume is the result of a measurement of traffic volume.

9. A method in accordance with patent claim 1, characterized in that the usage probability distributions of the hopping states are fixedly allocated to the base station transceivers specifically for each individual transceiver.

10. A method in accordance with patent claim 1, characterized in that the usage probability distributions of the hopping states are allocated to the transceivers of the base station dynamically in response to traffic load.

11. A method in accordance with patent claim 1, characterized in that the number of certain hopping states in the hopping pattern is higher than that of other hopping states.

12. A method in accordance with patent claim 11, characterized in that the hopping pattern is a pseudo-random sequence.

13. A method in accordance with patent claim 11, characterized in that the hopping pattern is a cyclic sequence.

14. A method in accordance with patent claim 11, characterized in that hopping patterns for connections are synchronised so that the connections interfere with one another as little as possible.

15. A method in accordance with patent claim 14, characterized in that the hopping patterns are synchronised so that the connections do not simultaneously use channels that cause significant mutual interference when used by the connections.

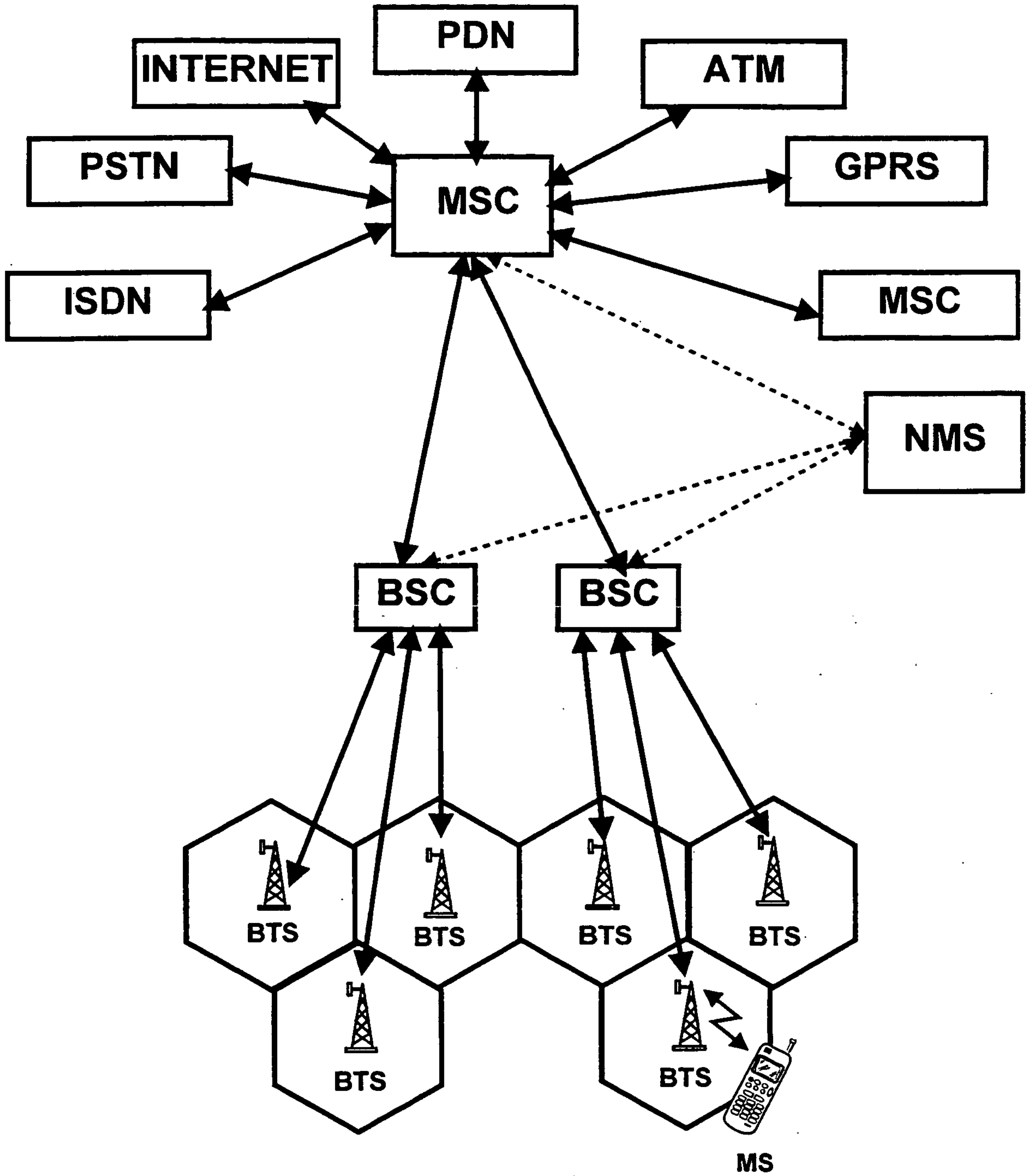
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FIG. 1.

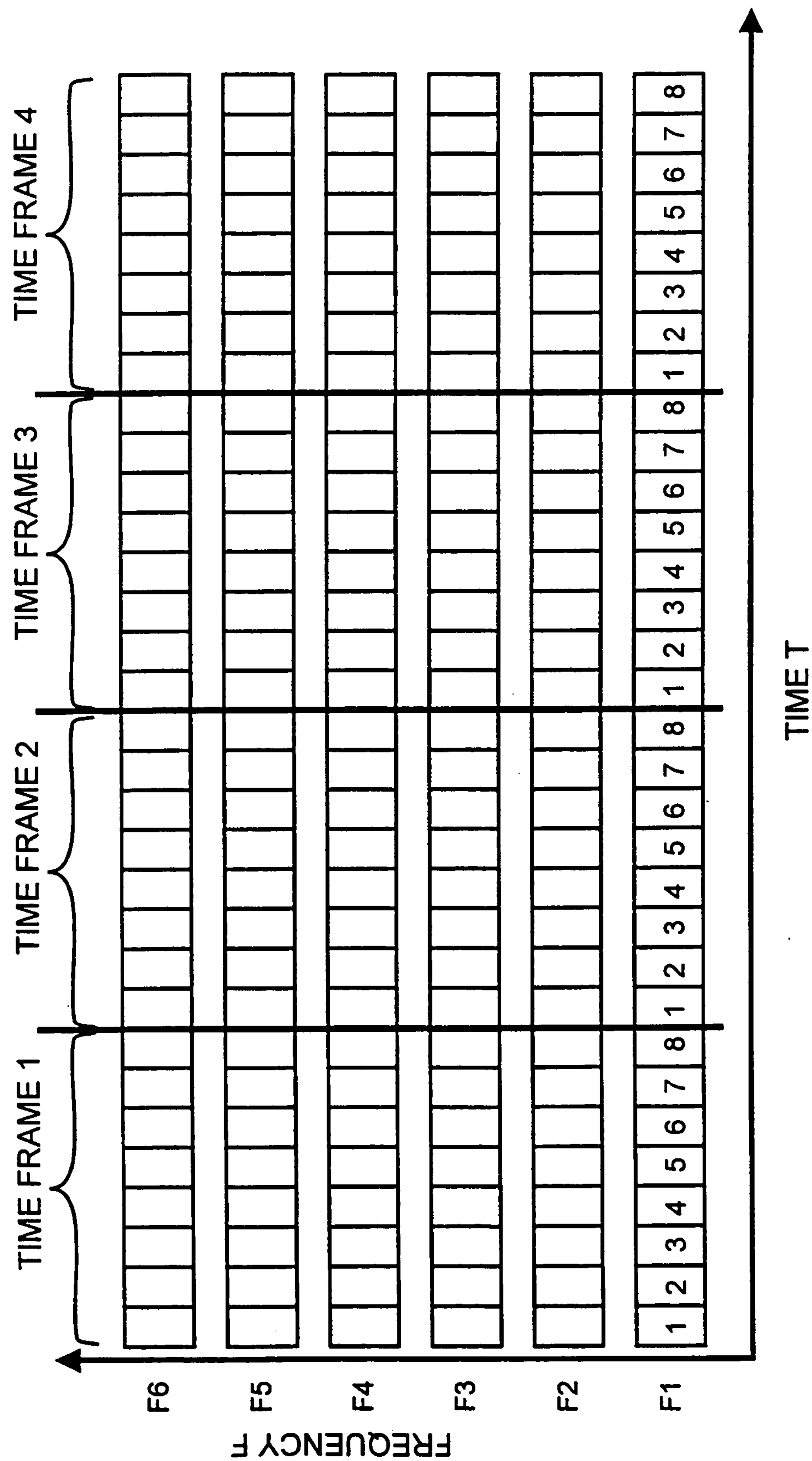
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FIG. 2

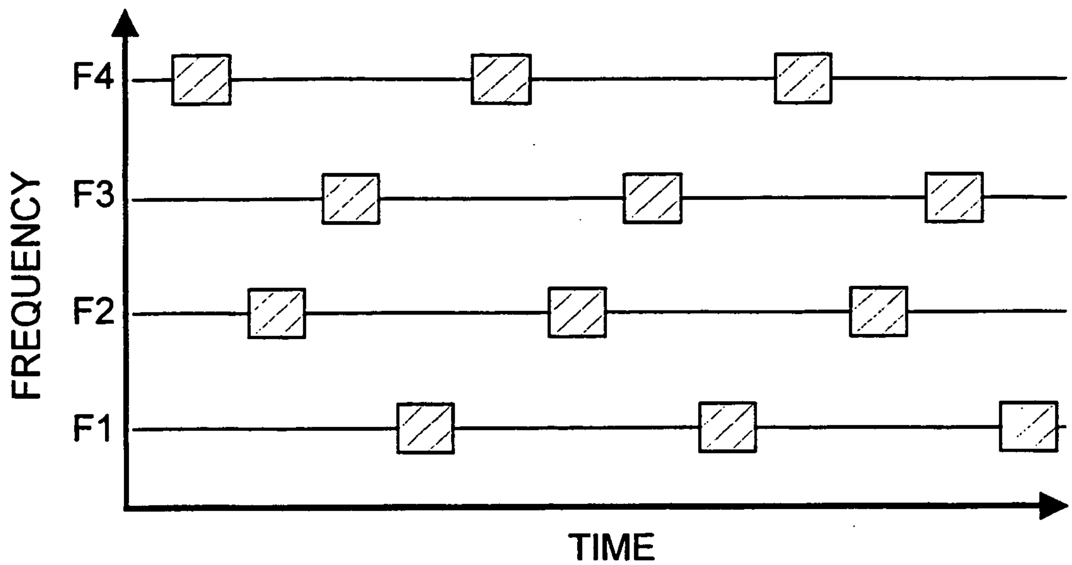
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FIG. 3.

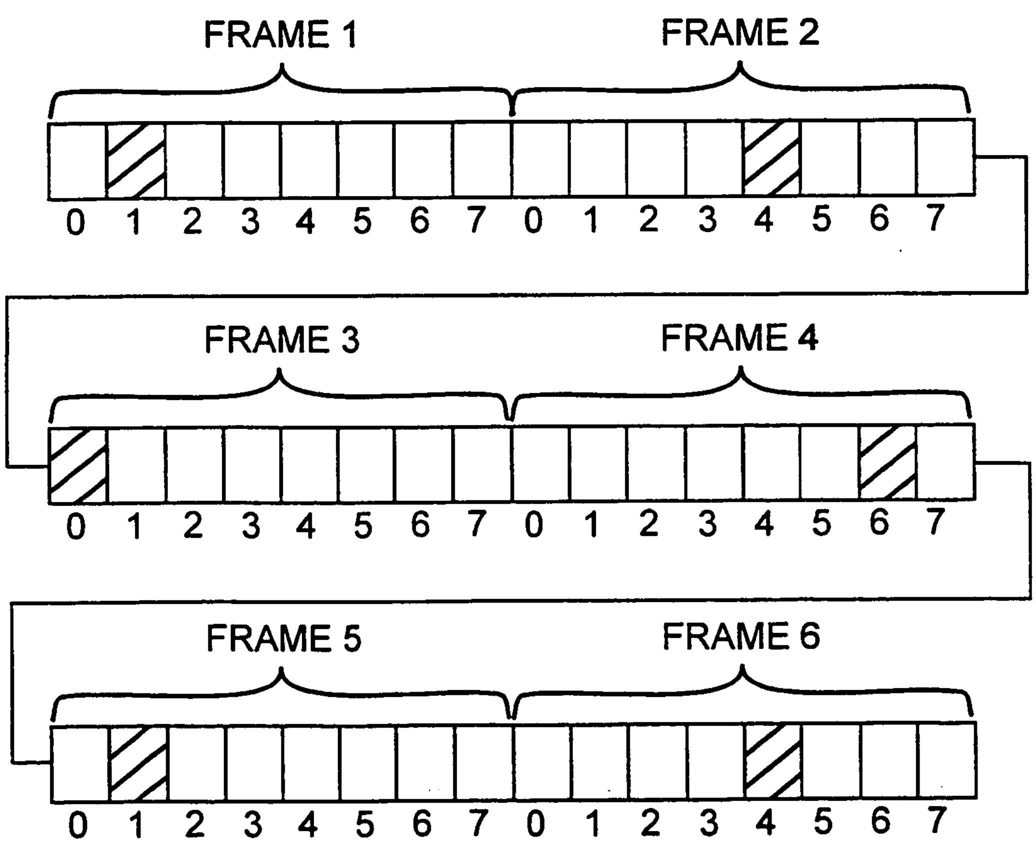
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FIG. 4.

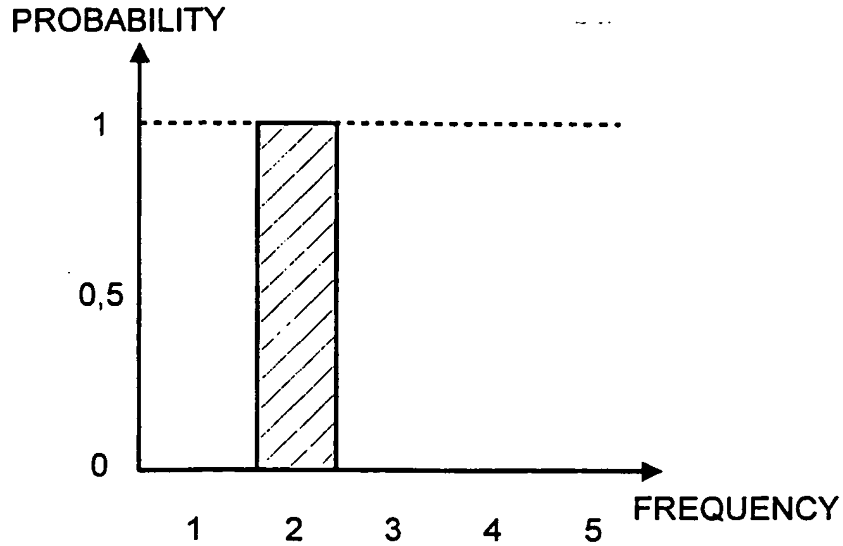

FIG. 5A.

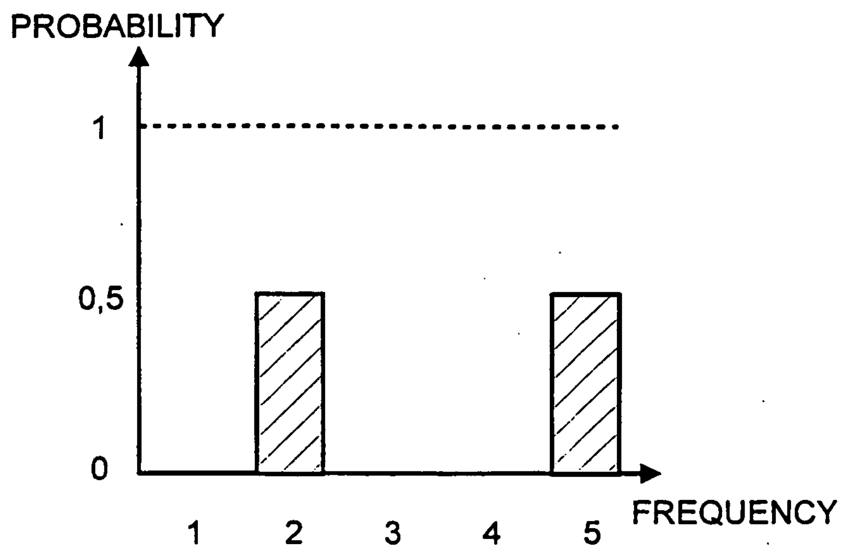

FIG. 5B.

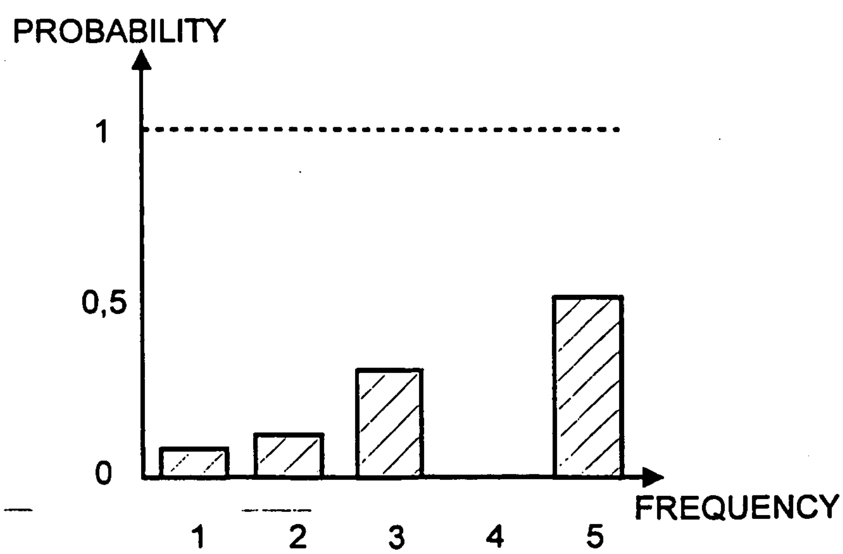

FIG. 5C.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 98/01030

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04Q 7/36, H04B 1/713
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H04Q, H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5581548 A (JON K. UGLAND ET AL), 3 December 1996 (03.12.96), column 14, line 15 - line 54	5,7,8,10
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X	WO 9602980 A1 (TELEFONAKTIEBOLAGET LM ERICSSON), 1 February 1996 (01.02.96), page 10, line 4 - page 13, line 12; page 21, line 15 - page 22, line 31; page 28, line 35 - page 29, line 15, page 30, line 34 - page 31, line 25	1-4,6,9, 11-15
Y		5,7,8,10
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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
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"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 June 1999	11 -06- 1999
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Peter Hedman/cs Telephone No. +46 8 782 25 00

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 98/01030

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT
Information on patent family members

03/05/99

International application No.
PCT/FI 98/01030

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